Real-Time Obstacle Detection & Avoidance during Mobile Robot Navigation in a Dynamically Changing Environment

Ph.D. Synopsis

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1. Background

1.1. Introduction

With the advent of the Internet of Things, mobile robot navigation is one of the fastest growing research fields. A mobile robot is a software-controlled machine that uses sensors and other technology to detect obstacles and move around its environment to reach its goal location. Mobile robots have become more prevalent in recent years because they can navigate any environment without guidance or a human operator. Mobile robots are being used to improve services and daily operations in various areas, including healthcare, household, businesses, industries, education, agriculture, security, and defence, etc. The demand for mobile robots has increased due to technological advancements and their tasks and services, such as lifting heavy things, surveillance, underwater exploration, lunar exploration, search and rescue operations, etc. Drones and humanoid robots are the best examples of mobile robots. Path planning is the core feature and a fundamental problem in mobile robot navigation. Finding the optimal collision-free path is one of the most challenging aspects of mobile robot navigation, as optimal path planning of mobile robots saves time and reduces capital investment. The navigation environments can be divided into two groups based on the prior information available: known environments and unknown environments. During the navigation task, the navigation environments may or may not change. Moving obstacles, in general, cause changes in navigation environments. If the obstacles on the path are static, the navigation environment is considered as the known environment. So, before planning a path, the robot needs detailed information about its surroundings in the known environment [1]. This information includes

the position of the robot and obstacles, which are initially processed by the algorithm. Then, a path from the start to the goal of the robot is constructed. A navigation environment is regarded as an unknown environment if the obstacles are dynamic. No prior knowledge of the environment is required in an unknown environment as various sensors are needed to sense the environment for obstacles [2]. In the case of known environments, the global navigation method is used to discover the optimal path based on prior knowledge, such as a map of the surroundings. But in the case of an unknown environment, the environment map is unavailable. So, the local navigation method, which is dependent on real-time sensory input obtained from the robot's sensors, is used. In either known or unknown environments composed of obstacles, the mobile robot requires finding the collision-free shortest path with the least possible time from the starting location to the goal location [3]. However, finding the best route for the robot in an unknown environment is difficult. Given the environment in which the robot may navigate, there may be multiple possible paths. The goal of most path planning algorithms is to find the optimal path, or at least a close approximation to it. This is crucial in search-and-rescue operations, because disaster victims may ask for assistance in life-or-death circumstances. Mobile robots can be used in various applications, including domestic, public sector, production, medical, bio-industrial, military and space exploration [4]. Collision-free path planning is required in all of these applications for mobile robots to complete their tasks. In all of these applications, the mobile robots use the building blocks to complete their navigation tasks [5] as shown in Fig. 1.

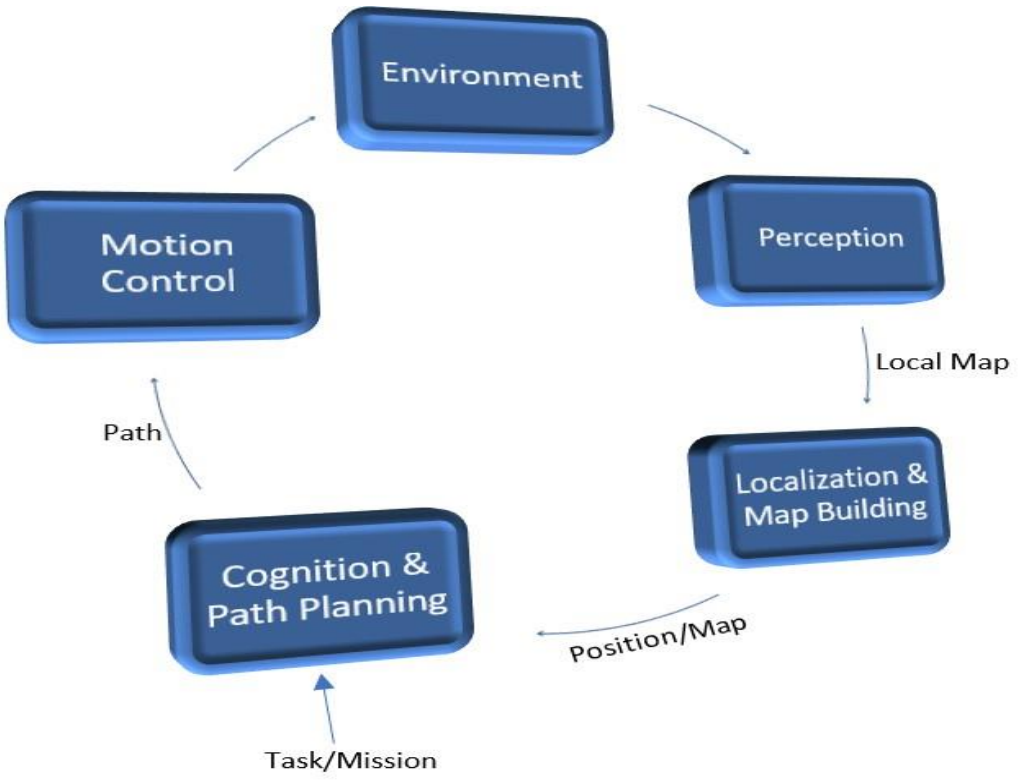

Figure 1: Mobile Robot Navigation Building Blocks

1.2. Optimization Criteria

There are several factors to consider while developing optimization criteria for path planning in mobile robots. To provide an optimal path, the following three optimization objectives must be considered.

a. Path Length (d)

The primary purpose of this objective is to find the shortest feasible path. All sub lengths from the starting location to the goal location will be added together to get the overall path length. The formula for this is as follows [6]:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (1)$$

In general, $d = \sum_{j=0}^{n-1} \sqrt{(x_{j+1} - x_j)^2 + (y_{j+1} - y_j)^2}$ (2)

Where in (2), n is the number of nodes from starting location to the goal location

b. Smoothness (s_p)

The smoothness objective aims for a path that is as straight as possible. This objective will assist in saving energy since the mobile robot will move through the path in a straight line with few turns, as opposed to a curved path that takes a lot more energy. The following equation [7] can be used to determine the smoothness of a path.

$$s_p = \sum_{j=1}^{m}(180^{\circ} - \theta_j) \quad (3)$$

Where, in (3), m is the number of angles produced from the starting location to the goal location, and θ_j is the angle value.

c. Saftey Degree (s_d)

Safety degree is critical for providing collision-free pathways, especially in environments where robots and humans interact. Safe path planning is essential, especially for mobile robots with a high degree of freedom operating in an unknown environment. Safety degree, which may also be used to indicate the collision probability, is defined as follows [6]:

$$s_d = \sum_{p=1}^{n-1} s_p = \begin{cases} 0 & , if \quad d \geq \lambda \\ \sum_{k=1}^{n-1} e^{\lambda - d_k} & , if \quad d < \lambda \end{cases} \quad (4)$$

Where in (4), d represents the shortest distance, and λ is the safety degree threshold.

1.3. Navigation Discipline

No doubt our society has accepted using robots to perform dangerous activities such as exploration of nuclear power plants. But now, robots are moving out of the factory to perform numerous human activities and assist us in our daily lives [8]. Robots work beyond our

imagination, thus creating a new world of autonomous agents. The incredible beauty of robots is that they can sense their environment with the help of sensors and intelligently execute their tasks to pursue their goals [9]. When we say robots, we mean the machines which make their own decisions through programming [10]. If a human being decides to pick up a piece of metal from the ground, he will come across the following steps: First and foremost is the visual thing, as his eyes need to see the piece of metal where precisely that is lying on the ground. The next step is that of stimulus sent to the brain. The brain responds to the same information and subsequently decides to pick up the piece of metal, and eventually, his hand picks up the piece of metal that is lying on the ground. This is true for robots as well. They undergo the same process as they imitate human eyes, brain, and hands. They have sensors instead of eyes, a control system instead of the brain, and effectors instead of eyes. Developing these components in a robot is challenging, as sensors must detect sounds and images efficiently and correctly. Effectors also ought to be fast and flexible enough to do what we instruct them to do, and the control system must make all decisions effectively to make effectors and sensors coordinate with each other to make work done efficiently and adequately. Navigation is a need for all mobile robots. The purpose of navigation is to find the way to the desired destination. This can be broken down into three components [11], as shown in Fig. 2.

- Where I am: The significant problem is the understanding of own location relative to the goal location
- Where I want to go: The goal of a navigating robot's task is to get to a distinct location. It could be at a distant place, or it could be just exploring the environment, or searching an area until some achievement criterion is fulfilled. There can be multiple tasks also, such as exploring the region on the right, but the robot batteries might be drained and

the charging station is situated on the left. Thus, these multiple tasks are then broken down into subtasks.

- How I get there: This could be interpreted as: move in the left direction, avoid obstacles as they are identified.

Figure 2: Navigation Disciplines

1.4. Navigation Components

The navigation components of mobile robots are shown in Fig. 3.

a. Control System

It serves as the robot's brain and planner for the tasks that the robot must complete. Also, the coordination between various mechanical and electrical components is done by the cognitive system. The cognition system organizes, analyses, and processes the data flowing in from the input sensors [12]. Models and algorithms included in the controller mostly determine how

the robot will interact with its environment, such as choosing the optimal path. Additionally, it might incorporate additional algorithms that create a map of the surrounding in case there is no prior information regarding the environment.

b. Sensors

Robot placement and localization activities can be accomplished with the use of sensors [13]. Additionally, they are employed in mapping [14]. They are also extremely beneficial in other application of robotics like object recognition [15].

c. Cognition

Cognition is the process of inquiring about information that has been observed and drawing sensible conclusions from that reasoning about how to behave.

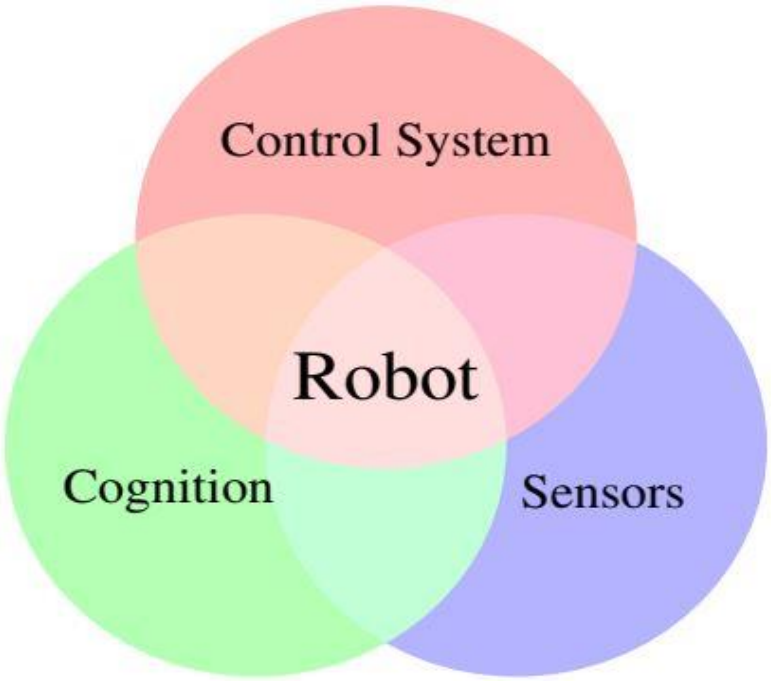

Figure 3: Navigation Components

2. Review of Literature and Identification of Research Gaps

2.1. Review of Literature

O. Khatib [16] was the first to suggest the potential field method for solving the problem of obstacle avoidance during mobile robot navigation. The robot is represented as a point and is treated as a particle under the influence of an artificial potential field. The purpose of this strategy is to steer the robot away from the repulsive field (obstacles) and drive it towards an attractive field (goal location), as shown in Fig. 4.

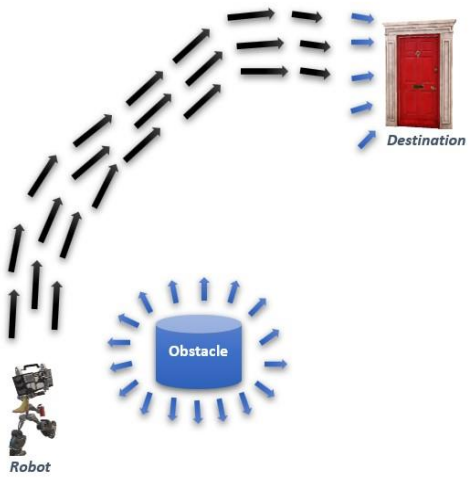

Figure 4: Artificial Potential Field Illustration

Several modifications and improvements of the potential field method have been suggested [17-18] since its original introduction by [16] to overcome its limitations, such as being caught in local minima. Because of its simplicity, this approach has been quite popular among researchers, but it is only useful in a known environment with fixed obstacles. To overcome the optimality problem, [19] proposes a safe path planning approach based on Voronoi diagrams. Also, [19] offered enhancements for effective path planning to increase efficiency and reduce limitations such as abrupt turns and large loops in the Voronoi diagram. To get path

optimality, [20] combines the potential field method, visibility graph, and Voronoi diagram as the hybrid methodology. It has been discovered that the method fails to find an optimal path. [21] employed artificial neural networks to address the robotic path planning problems and described how neural networks may help robotic path planners perform better. Because of its ability to provide optimum solutions in complex scenarios, artificial neural networks are generally utilized in search optimization and pattern recognition problems [22]. An artificial neural network-based path planner is developed that can plan paths for multi-robots at the same time while avoiding obstacles in an unknown environment [23]. However, there are several drawbacks to employing artificial neural networks. In certain circumstances, the training data necessary to produce statistically valid findings may be extremely enormous [34]. In [25], a genetic algorithm-based path planning method with variable-length chromosomes is presented. For a known environment, [26] suggested an application of genetic algorithm for the mobile robot navigation problem. [27] suggested a global path planner based on a genetic algorithm that decreases binary strings' length by translating 2D points to 1D points. Most studies have only used genetic algorithms to offer navigation in a known environment, while [28] suggested navigation in the presence of obstacles in an unknown environment. Numerous researchers have coupled the genetic algorithm with another intelligence algorithm to improve robot path planning outcomes to create a hybrid technique. In conclusion, the primary flaw in the genetic algorithm technique in robot path planning is that it is not effective in unknown environments. Because genetic algorithm operates on a grid map and has no control over population variety. Thus, genetic algorithm is combined with other algorithms improve robot path planning. [29] described the use of the ant colony algorithm for navigating mobile robots in an unknown environment. To tackle the path planning of a mobile robot, [30] presented a chaotic ant colony

system. The technique is not only more successful than the standard ant colony technique, but it also increases global search capabilities. The ant colony has a tremendous global search capability; even in unknown environments, it can identify a better path. However, the algorithm's early stages of convergence are slow, and it takes a long time to complete. [31] employed local neighbourhood versions of particle swarm optimization and observed that the suggested technique outperforms the genetic algorithm. [32] suggested a particle swarm optimization-based robot obstacle avoidance technique for both known and unknown environments. [33] compared several techniques such as particle swarm optimization, genetic algorithm, neural network, and fuzzy logic to find the optimum navigation path, concluding that fuzzy logic combined with particle swarm optimization provides the optimal results in terms of distance covered.

2.2. Identification of Research Gaps

The identified research gaps are as follows:

- Entrapment in local minima.
- Inability to handle maximum uncertainty.
- Need for exact environmental information.
- Robot collision problem in Visibility Graph method and non-optimality & non-convergence in Voronoi Graph method.
- Difficulty in deciding on the best rules and membership functions in case of fuzzy logic.
- High time complexity in genetic algorithm, and convergence occurs very soon. Moreover, it is not effective in unknown environments
- Parameter sensitivity in case of Particle Swarm Optimization
- Developing a neural network architecture to describe an unknown environment is

challenging.

3. Objectives/Methodology

3.1. Research Objectives:

The research objectives are as follows:

i. To propose and evaluate real-time obstacle detection & avoidance technique for mobile robot navigation in a dynamically changing environment.

ii. To identify the valid path towards the goal location using proposed technique.

iii. To carry out the performance comparison of proposed model with existing techniques.

3.2. Research Methodology:

The Research Methodology is shown in Fig. 5.

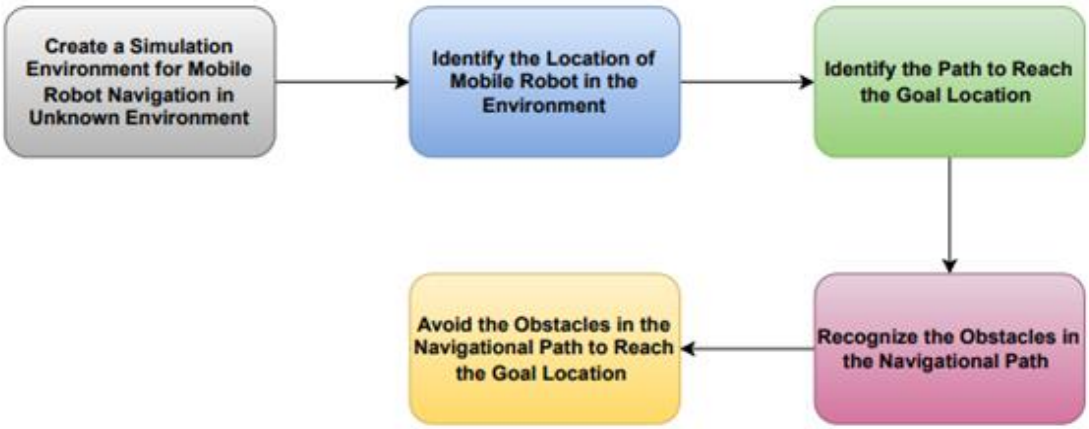
Create a Simulation Environment for Mobile Robot Navigation in Unknown Environment
Identify the Location of Mobile Robot in the Environment
Identify the Path to Reach the Goal Location
Recognize the Obstacles in the Navigational Path
Avoid the Obstacles in the Navigational Path to Reach the Goal Location

Figure 5: Research Methodology

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